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06 December 2000
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Department of the Air Force
30th Space Wing
Vandenberg AFB, CA 93437

Attention: SES (M. McCombs)

Subject: Space Launch Complex 4 (SLC-4) Potential Toxic Wetted Areas Study.

Reference: Contract F04684-97-C-0020
CDRL Item A002, Technical Report - Type 4
Task No. 10/01-508

Gentlemen:

This study is submitted in response to a 30 SW/SESI task for Hernandez Engineering, Inc., Vandenberg Operations to perform a review of Space Launch Complex 4 (SLC-4) propellant systems and operations to validate worst-case credible wetted areas for prediction of cold spill THZs (PHZs) for Titan II and Titan IV booster vehicle load propellant transfer operations.

An electronic copy of the study has been forwarded to Stan Aulabaugh, 30 SW/SESI.

Please contact [redacted] if you have any questions.

Very truly yours,

[redacted]
Program Manager
Vandenberg Operations

DES:JC:ba
Attachment: Comments
cc: 30 CONS/LGCZG (w/o atch)
File

Hernandez
Engineering Inc.

SPACE LAUNCH COMPLEX 4 (SLC-4) POTENTIAL TOXIC WETTED AREAS STUDY

Revision 1

05 December 2000

Prepared By:

Hernandez Engineering, Inc., Vandenberg Operations
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Summary

Wetted area values used for cold spill THZ (PHZ) planning for SLC-4 booster vehicle load propellant operations at SLC-4 were reassessed using a worst-case "credible/probable" approach to a spill, as opposed to an approach of worst-case "possible". Along with the specific system design features, risk mitigation factors to refine and improve acceptable work procedures were taken into consideration. These included steps from lessons learned and the incorporation of drop prevention devices.

The worst-case possible leak scenario for MST preparations prior to and during tower roll back was validated. Two (2) additional worst-case credible/probable leaks with wetted area predication scenarios for Titan propellant operations have been identified and are included below.

System Bleed-In/Propellant Loading:

> System bleed-in and dynamic propellant transfer operation during booster vehicle load with a maximum wetted area of 3.25 sq ft.

Fill and Drain Quick Disconnect (QD) Disengagement:

> Fill and drain flexible hose disconnection sequence should use the applicable wetted area for the vehicle loading station based on total fill and drain flexible hose volume. These quantities cannot be exceeded since the static head for the given commodity is contained in the fixed vertical plumbing on the umbilical tower and is physically isolated from any pressurization source prior to commencing the disconnection operation. Varying wetted area predictions are indicated in Figure 1 of this study.

MST Move Preps and Tower Roll-Back:

> This operation takes place late in the launch countdown sequence and presents the largest potential wetted area. During preparation sequences for MST roll back, including handrail removal and work platform retraction, the current wetted area calculations imposed in Appendix F of the Launch Complex Safety Plan should be continued, i.e., 4,000 sq ft for SLC-4E, and 5,200 sq ft for SLC-4W. The accompanying cold spill THZs for these wetted area predictions provide for worker and public safety during these periods of increased risk.

Foreword

This document satisfies the special analysis requirement under the Ground System Safety Analysis Contract (GSSAC) F04684-97-C-0020 and is being delivered as a CDRL Item A002 Technical Report.

Acknowledgements

HEI acknowledges the effort of Lockheed Martin System Safety personnel and the propellant system PIEs for SLC-4E and SLC-4W launch pads as instrumental in providing technical information used in this analysis.

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1. INTRODUCTION

This analysis is submitted in response to a 30 SW/SESI task for Hernandez Engineering, Inc., Vandenberg Operations to perform a review of Space Launch Complex 4 (SLC-4) propellant systems and operations to validate worst-case credible/probable wetted areas for prediction of cold spill THZs (PHZs) for Titan II and Titan IV booster vehicle load propellant transfer operations.

The objective of this analysis was to assess the SLC-4 current wetted area prediction values for propellant operations using a worst-case "credible/probable" (unlikely but could reasonably be expected to occur during the life-cycle of the system) approach to a spill, as opposed to an approach of worst-case "possible" (unlikely to occur, but within the realm of possibility).

1.1 SCOPE

Items addressed in this study are limited to the equipment and procedures required for specifically identified propellant transfer operations occurring at SLC-4E (Titan IV) and SLC-4W (Titan II). The propellant transfer systems at each of these locations consist of the following items:

- Storage tanks for providing short-term (i.e., one (1) launch cycle) storage of the required propellant.
- Transfer piping, including the pump, from the storage tank to the Propellant Loading Unit (PLU).
- The PLU component, which provides the necessary flow controls and measuring devices to perform calibrated propellant loading of the Titan core vehicle.
- Additional transfer piping from the PLU to a flex hose connection near the specific vehicle loading point.
- Flex hose(s) which provide the final link between the propellant transfer system (groundside) and the specific vehicle loading point (flight side). The flex hose terminus consists of a quick disconnect (QD) matched to an equivalent component on the vehicle. A self-sealing poppet exists on each side of this QD.

The assessment did not address the propellant loading unit (PLU), spacecraft loading on SLC-4, nor Ready Storage Vessel (RSV) operations. RSV operations were considered in an earlier study and therefore will not be repeated here. The PLU was excluded due to its static mode during propellant loading and its role as a component during the analyzed operations. Numerous flanged components existing in piping between and within the storage tank, the PLU and the flex hose connections were examined from a failure analysis perspective with the assessment that, outside of a catastrophic environmental influence, failure of these items were viewed as noncredible during normal propellant operations. Titan II spacecraft loading spill analysis wetted areas as currently provided by satellite vehicle contractor were accepted for purposes of this analysis and no further assessment was judged necessary on this operation. Titan IV spacecraft loading spill analysis wetted areas were not considered in this study due to the special operations nature of the various propellant loading operations.

1.2 REVIEW OF PREVIOUS STUDIES

In June 1987, Martin Marietta Denver Aerospace responded to a request by WSMC/SES to review its SLC-4 propellant operations to determine a credible spill scenario. An analysis was performed to identify credible spill scenarios and facilitate the prediction of realistic toxic hazard corridors for SLC-4 operations. Twelve (12) credible spill assumptions and three (3) operational spill locations with associated components were identified. Propellant Transfer Systems (PTS) at SLC-4E and SLC-4W were judged sufficiently similar such that credible spill scenarios outlines were valid for both pads. Assumptions were as follows: The most likely operations where leaks would occur during propellant transfer operations were identified as Vehicle, RSV, Tanker, ACS, and Payload load/unload. Catastrophic failure of a valve, QD, filter, hard-line, or hose resulting in gross external leakage of fluid was judged noncredible outside of a catastrophic event. The conclusion was that the most credible/probable time for a spill to occur was during a propellant transfer operation and a wetted area no larger than 3.25 sq ft would result.

Following publication of the credible spill analysis findings, 6595 ATG review and correspondence indicated that human error had not been factored into the analysis findings. It was their recommendation a factor of safety be applied to the maximum credible/probable spill area of 3.25 sq ft to allow for human error impacts in operations.

In June 1988 a study titled "Major Propellant Cold Spill Analysis for SLC-4" addressed two postulated worst-case spill scenarios that could occur during booster vehicle load or during tower preparations prior to MST roll back. Spills were postulated as a leak of propellant from the tanks near the bottom through either a 1-inch (slow leak) or 3-inch (fast leak) diameter hole. Wetted area predictions for each of the postulated leak scenarios were documented and reported to WSMC/SES as requested.

In October 1988 further analysis conducted by WSMC/SES, titled "SLC-4 Cold Spill Analysis", concluded that projected wetted areas resulting from a worst-case possible spill scenario should be used in propellant transfer planning. Although the worst-case credible/probable leak of 3.25 sq ft, as indicated in the Martin Marietta report was acknowledged as accurate, this value was not used in the conclusions of the WSMC/SES final report. The current wetted area predictions used for SLC-4 propellant transfer operations included in the Launch Complex Safety Plan are derived from the WSMC/SES analysis based on "worst-case possible" fault modes.

In February 1989 Martin Marietta added an addendum to the MMC Credible Spill Analysis Letter of 18 Jun 87. Acknowledging the potential for human error, the recommended factor of safety of ten (10) was applied to the original analysis findings. Martin Marietta concluded that the maximum credible/probable spill wetted area would be no larger than 32.5 sq ft.

Propellant transfer system (PTS) design and operation were also analyzed in the separate Integrated Accident Risk Assessment Reports (IARARs) for SLC-4E and SLC-4W. Potential hazards associated with various aspects of propellant usage were identified (e.g., exceeding commodity TLV, material compatibility and usage, specific system design and factors of operational safety) and subsequently mitigated to an acceptable level of risk as recorded in these documents. IARAR updates, made on a mission by mission basis, assess changes to these systems for safety impact. This "closed loop" methodology provides the basis by which the PTS meets established safe design criteria and operating guidelines. A number of the Martin Marietta studies mentioned in the above paragraphs exist as appendices in these reports.

The current Launch Complex Safety Plan SLC-4, Appendix F, implements wetted area values for the West and East pads per the WSMC/SE to 6595 ATG/TS correspondence of 19 October 1988. The SLC-4 Cold Spill Analysis report modified peak effective wetted areas calculated to the values of 5200 sq ft (SLC-4W) and 4000 sq ft (SLC-4E).

1.3 REVIEW OF WESTERN RANGE SAFETY REQUIREMENTS

Currently conservative values used for potential toxic wetted areas result in the implementation of toxic hazard zones and Tier 1, 2 or 3 areas which trigger stoppage of operations and evacuation of intersected facilities, thereby impacting planning and operation schedules.

The SLC-4 Launch Complex Safety Plan, Appendix F details the requirements for forecasts prior to any propellant flow, propellant tank pressurization, propellant vapor release to atmosphere, or any propellant transporting/handling where more than five (5) gallons substance are involved. THZ forecasts are generated in accordance with 30 SWI 91-106, which provides the toxic exposure limits for both hydrazine based fuels and nitrogen tetroxide oxidizer. Potential Hazard Zones (PHZs) are planning zones established prior to specific operations to assess risk should accidental cold spills or unplanned releases occur.

1.4 ASSUMPTIONS

The list of assumptions identified below was generated from two (2) primary sources. The first of these was the review of existing studies identified in Paragraph 1.2. A review of launch site booster processing procedures and test sequencing plans constituted the second source of information for this paragraph.

- The Propellant Transfer Systems (PTS) for both fuel and oxidizer at SLC-4E and SLC-4W are sufficiently similar in physical and operational characteristics, that the credible/probable spill scenarios outlined are valid for both pads, except as specifically noted.
- Standard accepted practices would be followed to limit the quantity of leakage. The Launch Complex Safety Plan including Appendix A, the Emergency Reaction Plan and Appendix B, Propellant Spill Plan and the SLC-4 Emergency Operations Guidelines (T3J-00S00-4C) document are

on hand during propellant operations and provide guidance for actions required in the event of a cold leak or spill.

- Catastrophic failure of a valve, quick disconnect (QD), filter, hard-line or flexible hose, which would result in gross external leakage of fluid from the system is not credible/probable except in connection with some catastrophic external influences. The spill potential regarding a catastrophic leak resulting from an external influence is already well documented in the previous spill analyses.
- A heavy drip type leak is credible/probable; a spray-type leak is not. The leakage rate is a function not only of system pressure, but also of the design and degree of failure of the involved component. A baseline leakage rate of 6.5 ounces per minute is assumed for use in this evaluation during propellant system bleed-in and dynamic propellant flow. The assumption is based on previous leak/spill history and on review of design engineering for related valves and quick disconnects.
- A decay-type leak and/or bubble leak check are performed on the entire propellant transfer system prior to liquid flow. This action is required by Lockheed Martin procedures prior to dynamic propellant transfer operations.
- A visual leak check verification of the propellant system, including at the vehicle interface, is made upon flow initiation, at the low flow rate of 50 gpm. This leak check verification is required by Lockheed Martin procedures.
- When QDs are being disconnected, leakage is checked for by procedure, and the presence of a leak in the poppets can be detected before the QD is fully disengaged. If a leak is detected, the procedure requires corrective action be taken including QD retightening.
- The previously predicted wetted area of 3.25 sq ft was accepted as accurate as it relates to propellant system bleed-in and booster vehicle load activity. This wetted area prediction times a safety factor of 10 (32.5 sq ft) is currently used in the LCSP per Range agreement.
- Assessments are for undiluted pure commodity.
- Wetted area is the surface area exposed to the atmosphere. Where the spill is unconfined, the surface area refers to a spill 0.1 inch deep. One (1) gallon liquid equates to 16.0416 sq ft surface area at a depth of 0.1 inches.
- A spill due to over-pressurization of a loaded vehicle propellant tank is not considered a credible/probable occurrence. Procedures require continuous monitoring of tank pressure during loading pressurization. Further, relief valves in the vent system set to open at slightly above the system's normal operating pressure IAW MIL-STD-1522 protect each tank.

2. Investigation and Analysis

A number of activities were accomplished during the investigative phase of this report. As summarized in paragraph 1.2, an extensive review of safety related documentation pertaining to the entire history of the Titan programs at Vandenberg AFB was conducted with a goal of distillation of material and analyses relevant to this task. In addition to this effort, information about the design and operations of the specific systems under consideration was obtained through complete site walk-downs and discussions with the responsible PIEs. Test sequence plans and booster processing procedures were reviewed as a further aid in establishing an understanding of the overall structure of propellant operations including the specifics of the operations. Verification of key part data and historical information contained in this report was requested from the appropriate organizations in Lockheed-Martin.

The approach used to determine the wetted surface area for THZ planning purposes, in accordance with 30th Space Wing Instruction 91-106 (Toxic Hazard Assessments), is derived, in part, from a 17 October 1988 study, "SLC-4 Cold Spill Analysis". However, the present study holds that the basic premise of this report is unsound. Applying a wetted area prediction for a catastrophic leak or spill to all propellant loading activity without regard to assessing the reliability of the system and evaluating the various system functions for determination of a credible/probable spill is not credible/probable for normal propellant operations.

In the present assessment "wetted area" prediction for propellant operations Is effected using the analysis for a "worst-case credible/probable" spill event, as opposed to an application of a "worst-case possible" spill scenario. The end-to-end system was analyzed for potential leak areas and evaluated to determine the maximum credible/probable spill area for each identified leak source. This approach involved an in-depth review of existing propellant loading procedures and pre-task verifications.

2.1 FAILURE CONSIDERATION

Although the potential for a flexible hose failure is remote, it was given consideration. The most credible/probable leak scenario during propellant transfer is that of a small quantity drip leak. Based on pre-task preparation prior to flow regarding this potential, i.e., end-to-end pneumatic leak checks at MOP, verification of vent and pressurization relief valves, the previously predicted wetted area of 3.25 sq ft or one (1) quart of liquid appears to be accurate. Based on overall fill and drain flexible hose factors of safety ranging from 12:1 to 17:1, a catastrophic failure of the hose was judged as not a credible/probable failure scenario.

The potential of a fill and drain hose failure was also analyzed. Based on an industry standard of a 4:1 factor of safety for flexible hose design (MIL-STD-1522 and T.O. 00-25-223), a catastrophic hose failure during normal propellant operations was viewed as a noncredible failure. This conclusion is supported by the additional factor of safety for each hose gained through the imposition of using the hoses in a system application where the maximum allowable working pressure is 150 psi. Table 1 below provides flexible hose design specifications extracted from the Lockheed-Martin standard part drawing for subject hose assemblies.

TABLE 1 – LOCKHEED-MARTIN FILL & DRAIN FLEXIBLE HOSE DESIGN SPECIFICATION

HOSE ID (in)	MAX ALLOWABLE WORKING PRESSURE (PSI)	MIN C/L BEND RADIUS	
		PERMANENT BENDS (in)	INTERMITTENT FLEXING (in)
2	2000	5.0	16.0
2 1/2	1500	6.0	17.0
3	1300	7.3	20.0

Table 2 below reflects the overall factor of safety for each flexible hose used in the propellant transfer system fill and drain.

TABLE 2 - FILL AND DRAIN FLEXIBLE HOSE OVERALL FACTORS OF SAFETY

HOSE ID (in)	DESIGN MAX WORKING PRESSURE (4:1)	SYSTEM MAX WORKING PRESSURE (psi)	HOSE FACTOR OF SAFETY DESIGN REQUIREMENTS + IMPOSED MAX SYSTEM PRESSURE
2	2000	150	17:1
2 1/2	1500	150	14:1
3	1300	150	12:1

A pressure build-up in excess of 1800 psi would be needed in order to adversely effect the integrity of the fill and drain flexible hoses. This pressurization scenario is not viewed as a credible/probable event due to inclusion of relief valves in the system design, which operate at pressures slightly above the system maximum operating pressure (MOP).

This study validated the conclusions of the 18 June 1987, Lockheed Martin study, "SLC-4 Credible Spill Analysis", in which 3.25 sq ft wetted area was presented as the maximum leakage expected during a wide variety of propellant transfer operations including booster vehicle load. This wetted area equated to a capacity of approximately one (1) quart. Spill containment to capture approximately five (5) gallons of commodity was procedurally integrated into the disconnection sequence.

During the course of this study, a failure mode not considered during the original analysis was analyzed. This was defined as the potential leakage from the fill and drain flexible hose QDs during disengagement.

A combination of procedural steps and vehicle propellant system specifics preclude mass leakage from the vehicle portion of the QD connector. However leakage from the ground portion of the quick disconnect was judged to be a credible/probable leak source.

Discussions with the responsible PIE indicated the maximum credible/probable spill potential would be a loss of commodity equaling the total volume of the fill and drain flexible hose assemblies. These maximum volumes and projected wetted areas for each vehicle loading operation are indicated in Figure 1. These quantities cannot be exceeded since the static head for the given commodity is contained in the fixed vertical plumbing on the umbilical tower and the propellant system is physically locked off from any pressurization source prior to the commencing the operation.

2.2 RISK MITIGATION FACTORS

The following list is a compilation of risk mitigation factors considered in the evaluation of worst-case credible/probable leak scenarios during booster vehicle load and other dynamic propellant flow operations. Each of these factors contributes to minimize the possibility of an uncontrolled leak or spill or aids in the early identification of an anomaly so that appropriate action can be initiated:

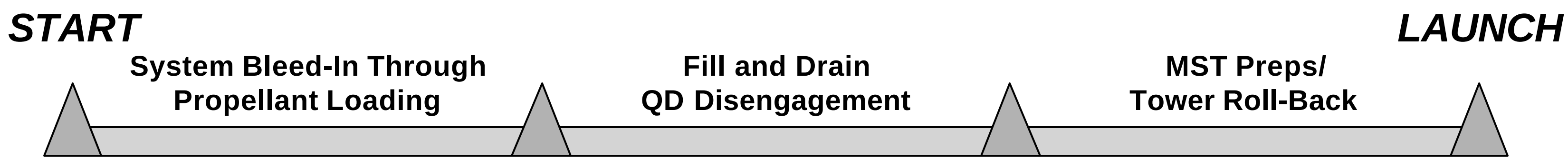
- During propellant loading activities, a display is available to indicate the exact propellant on board should a leak or spill occur.
- Propellant flow operations are monitored at specific locations and corrective action can be implemented rapidly should an anomaly become evident.
- Cameras are located to monitor critical areas during dynamic flow operations.
- In the event of a leak, powering down the propellant pump would rapidly decrease propellant flow within the system.
- By procedure, low flow rates are verified leak free prior to transitioning to the higher fill rates.
- Standard procedures will be accomplished to limit the quantity of leakage.

- Transfer plumbing from the supply vessel to the vehicle-loading interface is bled-in minimizing the potential for a leak after initiation of dynamic propellant flow.
- Precautions to prevent leakage/spill and the spread of small spills or leaks prior to the initiation of dynamic propellant flow minimize this potential and effectively control any significant liquid spread.
- Relief valves in the propellant transfer system protect from damage due to a pressure increase related to thermal heating of propellant locked up within the system. Relief valves are set to open at a pressure that adequately protects the transfer system plumbing.
- Fill and drain flexible hoses designed to an industry standard with a factor of safety of four (4) are used well below their design maximum allowable working pressure. The reduced maximum allowable working pressure, limited to 150 psi, results in an effective factor of safety of at least 12 for any of the hose combinations.
- Strict requirements are in force in the vicinity of the launch vehicle and other flight hardware to prevent potential damage from dropped objects. This includes a requirement to tether all tools and loose equipment that could be inadvertently dropped if not controlled in other approved ways.
- Debris nets and drop prevention provisions providing protection of exposed rattle space between the launch vehicle and work platforms have been incorporated to catch dropped objects before they can fall to a lower level.
- Validated test procedures, proven effective through continuous usage, are used as strict control for all propellant transfer operations.
- End-to-end system and pneumatic leak checks are conducted at the system maximum operating pressure (MOP), and would identify potential leak sources prior to the introduction of propellants into the system.
- Vent and Pressurization leak checks are conducted prior to propellant operations. These checks, including actuation of system relief valves at a pressure above MOP, i.e., 10% above, ensure that an over pressurization potential does not exist within the system.
- Effective spill containment is incorporated in the design of the launch complex.
- Corrective actions regarding “lessons learned” from other spills and leaks, including experience on the East Coast, are incorporated into the transfer systems to enhance their reliability, i.e., additional relief valves were installed in the system following a propellant release at CCAS to eliminate the potential for a similar occurrence at Vandenberg.

3. Analysis Results

- This study revealed no potential catastrophic failure points within the existing propellant transfer system with the exception of possible vulnerability during MST move preparations and MST roll-back.
- The most credible/probable leak sources identified were at flanged connections in the propellant transfer systems, at the propellant fill and drain quick disconnects, and at flexible hose sections within the transfer system. The maximum spill credible/probable would be attributed to loss of commodity equaling the total volume of the fill and drain flexible hose assemblies. These maximum volumes and projected wetted areas for each vehicle loading operation are indicated in Figure 1.
- Component selection for the propellant transfer system is compliant with contracted Range Safety requirements and pressure system design is compliant with the Range Safety requirements and the requirements of MIL-STD-1522.
- Defined maximum allowable working pressure for Fill and Drain flexible hose sections (150 psi) is significantly below the hose design maximums and provides an additional factor of safety with a resultant overall factor of safety of at least 12:1 for any combination of flexible hoses used for flexible plumbing connection.
- The respective propellant loading system product integrity engineers (PIE) at SLC-4 have incorporated “lessons learned” into the SLC-4 propellant transfer system and are trained to react to system anomalies, thereby improving the overall system reliability.
- Using "worst-case possible" spill scenarios for THZ plot calculations is not warranted. Using "worst-case credible/probable" is warranted and recommended given system design and risk mitigation factors taken to minimize the risk of a leak or spill.
- Flexible hoses used in conjunction with the Fill and Drain Quick Disconnect plumbing are not subjected to periodic tests.
- Spill containment currently incorporated into test procedures regarding disengagement of the Fill and Drain QD is not properly sized to accommodate a spill in excess of five (5) gallons credible/probable (see A.1.3 - Table 1).

Predicted Worst-Case
Credible Maximum Wetted Areas



VEHICLE LOADING STATION

- 3.25 sq ft

• Stage I Fuel, SLC-4E	287 sq ft
• Stage II Fuel, SLC-4E	163 sq ft
• Stage I Oxidizer, SLC-4E	343 sq ft
• Stage II Oxidizer, SLC-4E	136 sq ft
• Stage I Fuel, SLC-4W	109 sq ft
• Stage II Fuel, SLC-4W	119 sq ft
• Stage I Oxidizer, SLC-4W	100 sq ft
• Stage II Oxidizer, SLC-4W	92 sq ft

• SLC-4E	4000 sq ft
• SLC-4W	5200 sq ft

Figure 1

4. Conclusions

Based on the findings of this study, potential wetted areas were identified dependent on the particular sequence of propellant operation. The three worst-case credible/probable leak scenarios with wetted area predictions are:

- System bleed-in and dynamic propellant transfer operations during booster vehicle load should use a maximum wetted area of 3.25 sq ft.
- Fill and drain flexible hose disconnection sequence should use the applicable wetted area as indicated in Figure 1, VEHICLE LOADING STATION.
- During preparation sequences for MST roll back, including handrail removal, the current wetted area calculations imposed in Appendix F of the Launch Complex Safety Plan should be imposed, i.e., 4,000 sq. ft for SLC-4E, and 5,200 sq ft for SLC-4W.

The revised wetted area predictions listed in Figure 1 of this study reflect worst-case credible/probable spill calculations based on in-depth system analysis and credible/probable leak scenarios.

A worst-case possible spill scenario, that of spilling an extremely large volume of commodity, is a potential only when the launch vehicle is fully loaded. The spills postulated in the previous 30 SW/SES analysis are credible/probable events when MST move preparations are in progress and during the tower roll back operation. The existing wetted area predictions can be used during these activities without impacting launch complex work activity. The MST is not moved until late in the launch countdown sequence and it occurs after the pad has been evacuated of all non-essential personnel.

5. Recommendations

5.1 SLC-4 Titan Toxic Wetted Areas Study Recommendations

- Consider revision of the SLC-4 LCSP, Appendix F and cold spill THZ predictions for the associated operational sequences based on proposed wetted area predictions (See Table 3 below).
- Base THZ planning on the identified values derived from a graduated spill scenarios depending on the operational sequence and reflect the maximum credible/probable spill or release for the given operation. New information regarding the varying wetted area predictions needs to be compiled and provided to the 30th Weather Squadron to ensure accurate THZ plots for the various operations described herein.

Table 3 - Current/Proposed Launch Complex Safety Plan (Appendix F)

SLC	OPERATION/AREA	CURRENT WETTED AREA (sq ft)	PROPOSED WETTED AREA (sq ft)
4E	BV LOAD (FUEL)	4000	3.25
4E	SYSTEM BLEED IN (FUEL)	N/A	3.25
4E	STAGE I FUEL FILL AND DRAIN QD DISCONNECTION	N/A	287
4E	STAGE II FUEL FILL AND DRAIN QD DISCONNECTION	N/A	163
4E	SYSTEM BLEED IN (OXIDIZER)	4000	3.25
4E	STAGE I OXIDIZER FILL AND DRAIN QD DISCONNECTION	N/A	343
4E	STAGE II OXIDIZER FILL AND DRAIN QD DISCONNECTION	N/A	136
4E	MST MOVE	N/A	4000

SLC	OPERATION/AREA	CURRENT WETTED AREA (sq ft)	PROPOSED WETTED AREA (sq ft)
4W	BV LOAD (FUEL)	5200	3.25
4W	SYSTEM BLEED IN (FUEL)	N/A	3.25
4W	STAGE I FUEL FILL AND DRAIN QD DISCONNECTION	N/A	109
4W	STAGE II FUEL FILL AND DRAIN QD DISCONNECTION	N/A	119
4W	SYSTEM BLEED IN (OXIDIZER)	N/A	3.25
4W	STAGE I OXIDIZER FILL AND DRAIN	N/A	100

	QD DISCONNECTION		
4W	STAGE II OXIDIZER FILL AND DRAIN QD DISCONNECTION	N/A	92
4W	MST MOVE	N/A	5200

5.2 VALUE ADDED OBSERVATIONS/PROGRAM ENHANCEMENT CONSIDERATIONS

The following observations, although not directly associated with the task of analyzing the projected wetted area predictions, may enhance the safety effectiveness of propellant transfer operations and improve the overall reliability of the transfer system. Each of these observations/enhancements should be examined for possible inclusion in propellant loading/transfer operations.

- Detailed documentation of all propellant spills and inadvertent toxic releases be examined with the goal of continuously evaluating potential spill areas as well as serve as an empirical aid to updating wetted area predictions.
- Wetted area predictions listed in the Launch Complex Safety Plan should be periodically reviewed and updated as necessary. Planning for worst-case possible catastrophic events should be documented in the applicable disaster preparedness planning documents and they should be readily available.
- Provide spill containment accommodations at the source of known or suspected leak areas, i.e., at the fill and drain QDs and at connections or flanges susceptible to leakage.
- Consider adoption of periodic retest of flexible hoses not permanently installed in the propellant transfer system.

Appendices

A.1 CALCULATIONS

A.1.1 - Fill and Drain Flexible Hose Volume Conversion - SLC-4E

FACILITY	Part Number/ Function	Length (in)	Diameter (in)	Volume (in^3)	Capacity (gal)
4E	32E22E5340T Stage I Fuel	534	3.0	3774.632	16.34
4E	32E16E32FN036K Stage I Fuel	36	2.0	113.098	0.49
4E	32E16E32FN078K Stage I Fuel	78	2.0	245.045	1.061
4E	32E22Y428OT Stage II Fuel	428	2.50	2100.945	9.095
4E	32E16E32FN078K Stage II Fuel	78	2.0	245.045	1.061
4E	32E22E6440T Stage I Oxidizer	644	3.0	4552.178	19.706
4E	32E16E32FN106K Stage I Oxidizer	106	2.0	333.010	1.442
4E	32E16E32FN018K Stage I Oxidizer	18	2.0	56.549	0.245
4E	32E16E32FN096K Stage II Oxidizer	96	2.0	301.594	1.306
4E	32E16E32BN528K Stage II Oxidizer	528	2.0	1658.765	7.181

A.1.2 - Fill and Drain Flexible Hose Volume Conversion - SLC-4W

Facility	Part Number Function	Length (in)	Radius (in)	Volume (in^3)	Capacity (gal)
4W	32E22E2040T Stage I Oxidizer	204	1.5	1441.26	6.239
4W	32E22E2220T Stage I Fuel	222	1.5	1568.43	6.79
4W	32E16E32BN420T Stage II Oxidizer	420	1.0	1318.8	5.709
4W	32E22Y3480T Stage II Fuel	348	1.25	1707.375	7.391

A.1.3 - Table 1 – Fill and Drain Flexible Hose Wetted Area Predictions

Booster Vehicle Loading Operation	Total Combined Capacity Fill and Drain Flexible Hoses (gal)	Total Wetted Area (sq ft)
Stage I Fuel, SLC-4E	17.89	287
Stage II Fuel, SLC-4E	10.16	163
Stage I Oxidizer, SLC-4E	21.39	343
Stage II Oxidizer, SLC-4E	8.49	136
Stage I Fuel, SLC-4W	6.79	109
Stage II Fuel, SLC-4W	7.39	119
Stage I Oxidizer, SLC-4W	6.24	100
Stage II Oxidizer, SLC-4W	5.71	92

Note: Oxidizer - Nitrogen Tetroxide (N_2O_4)
Fuel - Aerozine 50 (A-50)

A.2 LCSP SLC-4, APP F, TOXIC HAZARD ZONE (THZ) CLEARANCE PLAN TABLES

A.2.1 Table F1 - Fuel Operations THZs, SLC-4 West

THZ NO.	SLC	WETTED AREA (SQ FT)	VAPOR FLOW RATE (LB/MIN)	ELEVATION (FT)	OPERATION AREA
1W-F	4W	5200	N/A	12	BV LOAD RB
2W-F	4W	1250	N/A	12	FHA/RSV
3W-F	4W	500	N/A	12	SV LOAD
4W-F	4W	300	N/A	12	PTU CXLED
5W-F	4W	32	N/A	100	HLC
6W-F	4W	N/A	8	200	FUEL VENT

*THZ NUMBERS 1-5 RELATE TO PHZs, WHILE 6 RELATES TO AN EHZ.

A.2.2 Table F2 - Fuel Operations THZs, SLC-4 East

THZ NO.	SLC	WETTED AREA (SQ FT)	VAPOR FLOW RATE (LB/MIN)	ELEVATION (FT)	OPERATION AREA
1E-F	4E	4000	N/A	12	BV LOAD RB
2E-F	4E	2200	N/A	12	FTP
3E-F	4E	1600	N/A	12	FHA/RSV
4E-F	4E	500	N/A	100	SV LOAD
5E-F	4E	300	N/A	12	PTU CXLED
6E-F	4E	N/A	8	200	FUEL VENT

*THZ NUMBERS 1-5 RELATE TO PHZs, WHILE 6 RELATES TO AN EHZ.

A.2.3 Table F3 - Oxidizer Operations PHZs, SLC-4 West

THZ NO.	SLC	WETTED AREA (SQ FT)	VAPOR FLOW RATE (LB/MIN)	ELEVATION (FT)	OPERATION AREA
1W-O	4W	5200	N/A	12	BV LOAD RB
2W-O	4W	1400	N/A	12	OHA/RSV
3W-O	4W	500	N/A	12	SV LOAD
4W-O	4W	300	N/A	12	PTU LOAD
5W-O	4W	N/A	49	200	OX VENT

A.2.4 Table F4 - Oxidizer Operations PHZs, SLC-4 East

THZ NO.	SLC	WETTED AREA (SQ FT)	VAPOR FLOW RATE (LB/MIN)	ELEVATION (FT)	OPERATION AREA
1E-O	4E	4000	N/A	12	BV LOAD RB
2E-O	4E	2200	N/A	12	OTP
3E-O	4E	1600	N/A	12	OHA/RSV
4E-O	4E	500	N/A	100	SV LOAD
5E-O	4E	300	N/A	12	PTU CXLED
6E-O	4E	N/A	0.133	200	OVS
7E-O	4E	N/A	49	200	OX VENT

*6E-O IS AN EHZ FOR SCRUBBER; 7E-O IS USED ONLY IF THE SCRUBBER HAS FAILED.
**1E-O WILL BE USED FOR TVC TANK PRESSURATION.

A.3 Study Reference List

- 30 SWI 91-106, Toxic Hazard Assessments, 30 December 1998.
- 87-v/o-0426 (MMDA), SLC-4 Credible Spill Analysis, 18 June 1987.
- 88-v/o-0267 (MMSLS), Analysis Document for SLC-4, 21 July 1988. [S. L. Boswell, (MMA), Major Propellant Cold Spill Analysis for SLC-4, 21 June 1988].
- EWR 127-1, Range Safety Requirements, 31 March 1997.
- LSO-600015-7612, Toxic Hazard Corridor Calculations, 05 January 1987.
- MIL-STD-882, Standard Practice for System Safety, Rev D, 10 February 2000.
- T3J-00S00-4C, Emergency Operations Guidelines, PCN 08.
- T3J-WLCSP-4C, Launch Complex Safety Plan SLC-4, Rev D, 31 July 1997.
- WSMC/SE to 6595 ATG/TC, SLC-4 Cold Spill Analysis, 19 October 1988. [L. A. Cotton (WSMC/SES), SLC-4 Cold Spill Analysis, 17 October 1988].

A.4 ACRONYMS AND TERMS

AFTOX - A chemical dispersion model developed by the Air Force used to plot toxic hazard zones (THZs).
Cold Spill - Release of toxic propellants in liquid or vapor form from a propellant transfer or vent operation. Propellant combustion does not occur.
Credible - Offering reasonable grounds for being believed.
Credible/Probable - see Worst Case Credible/Probable (below).
Credible spill - A potential spill, the size of which is predicted based on system and component design factors, as applied to normal operations using the specific hardware/configuration at SLC-4. It is further based on a reasonably experienced crew using time proven hardware and procedures. The degree to which these factors influence the occurrence of system/component failure or personnel error or the severity of the effects thereof will determine the likelihood and extent of a potential spill.
Essential Personnel - those personnel who do not meet the requirements of mission-essential personnel, but may be permitted within safety control areas to prevent a mission impact; all requests to enter require Range Safety approval on a case-by-case basis.
in - Inches.
MCE - Maximum Credible Event.
Mission-Essential Personnel - the minimum number of persons necessary to successfully and safely complete a hazardous or launch operation and whose absence would jeopardize the completion of the operation; this designation also includes people required to perform emergency actions according to authorized directives, persons specifically authorized by the Wing Commanders to perform scheduled activities, and those personnel in training. The Range Users and Wing Commanders determine, with Range Safety concurrence, the number of mission-essential personnel allowed within Safety Clearance Zones or Hazardous Launch Areas; see also Safety Clearance Zones and Hazardous Launch Area.
MAWP - Maximum Allowable Working Pressure; the maximum pressure at which a component or system can continuously operate based on allowable stress values and functional capabilities.
MEOP - Maximum Expected Operating Pressure; the highest pressure that a pressure vessel, pressurized structure, or pressure component is expected to experience during its service life and applicable operating environments; synonymous with maximum operating pressure (MOP) or maximum design pressure (MDP); includes the effect of temperature, pressure transients and oscillations, vehicle quasi-steady and dynamic accelerations and relief valve operating variability.
MOP - Maximum Operating Pressure; the maximum operating pressure a system will be subjected to during planned static and dynamic conditions.
Operation-Essential Personnel - The minimum number of personnel required to accomplish a specific operation.
Potential Hazard Zone (PHZ) - Planning zone established prior to a specific operation to assess risk should an accidental cold spill or unplanned release, or a hot spill catastrophic abort occur. Zones are based upon the worst-case credible emission rate or source strength for a specific operation. PHZ may have a Zone 1, 2, or 3 for N2O4/NO2/HCl. PHZ may have a Zone 2 or 3 for hydrazine-family propellants.
QD - Quick Disconnect.
RSV - Ready Storage Vessel.
SLC - Space Launch Complex.
Toxic Hazard Zone (THZ) - A generic term which describes an area in which predicted concentration of propellant or toxic byproduct vapors or aerosols may exceed acceptable tier levels. Predictions are based on analyzing potential source strength, applicable exposure limit, and applicable meteorological conditions.
Tier 1 - An airborne exposure level (maximum concentration) which poses no hazard to the general population but which may affect certain sensitive individuals (e.g., asthmatics, individuals with emphysema, and certain other lung diseased people). Tier 1 separates Zone 1 from the area where no controls are required.

Tier 2 - An airborne exposure level (maximum concentration) which may cause short term symptoms but which most individuals could endure without experiencing or developing irreversible or other serious health effects or symptoms which could impair their ability to take protective action. Tier 2 separates Zone 2 from Zone 1.
Tier 3 - An airborne exposure level (maximum concentration) based on the NIOSH IDLH values. Tier 3 separates Zone 3 from Zone 2.
Toxic Hazard Zone (THZ) - A generic term which describes an area in which predicted concentration of propellant or toxic byproduct vapors or aerosols may exceed Acceptable Tier Levels - Predictions are based on analyzing potential source strength, applicable exposure limit, and meteorological conditions. THZs are plotted for potential, planned and unplanned propellant releases and launch operations.
Worst-case - Most unfavorable specific scenario.
Worst-case possible – A potential spill resulting from a catastrophic release without considering the system and component design factors of safety and reliability or risk mitigation factors imposed to prevent such occurrence.
Worst-case credible/probable –The spill potential which exists after analysis of a specific operation has been completed (including relevant system and component design factors, operational test sequence plan location, equipment test and procedural controls established to mitigate the risk of a spill). This is also referred to in the study as "credible/probable".

A.5 TITAN SLC-4 ASSESSMENT TASKS

A.5.1 - East Pad - Titan IV Systems and Operations

A.5.1.1 - Tools for the Assessment:

PROCEDURE No.	PCN#	OPERATION	OWNER
T8K-08A51-4E	3	Transfer Fuel from Delivery Trailer to RSV	McGee
T8K-08A52-4E	3	Transfer OX from Delivery Trailer to RSV	McGee
T8K-08E03-4E	2	Oxidizer Loading	McGee
T8K-08E04-4E	2	Fuel Loading	McGee
T8K-08E10-4E	2	Vehicle Fuel Tank Pressure Verify/Adjust	McGee
T8K-08E11-4E	2	Vehicle Oxidizer Tank Pressure Verify/Adjust	McGee
T8K-08S01-4E	1	Vehicle Oxidizer Unloading	McGee
T8K-08S02-4E	1	Vehicle Fuel Unloading	McGee
T8K-08S51-4E	1	Fuel RSV Unloading	McGee
T8K-08S52-4E	1	Oxidizer RSV Unloading	McGee

A.5.2 - West Pad - Titan II Systems and Operations

A.5.2.1 - Tools for the Assessment:

PROCEDURE No.	PCN#	OPERATION	OWNER
T2K-08A50-4W	18	Vehicle Pressurize-Vent System Functional Checkout	McGee
T2K-08A51-4W	15	Fuel Ready Storage Vessel Filling	McGee
T2K-08A52-4W	11	Oxidizer Ready Storage Vessel Filling	McGee
T2K-08C13-4W	15	Stage I and Stage II Oxidizer Tank Leak-Checks	Ramirez
T2K-08C67-4W	9	Propellant Fill-Drain Connectors Leak-Check	McGee
T2K-08E03-4W	15	Oxidizer Loading	Troeger
T2K-08E04-4W	13	Fuel Loading	Troeger
T2K-08E14-4W	3	ACS Hydrazine Loading	Ramirez
T2B-08E20-4W	2	SV Propellant Loading	Ramirez (G-6/9)
T2E-08E20-4W	1	SV Propellant Loading	Ramirez (G-12/14)
T2K-08S 1-4W	xxxx	SV N2H4 Unloading	Troeger
T2K-08S01-4W	11	Vehicle Oxidizer Unloading	McGee
T2K-08S02-4W	8	Vehicle Fuel Unloading	McGee

T2K-08S09-4W	0	ACS Hydrazine Unload	Ramirez
T2K-08S51-4W	4	Unload Fuel RSV	Scheffler
T2K-08S52-4W	4	Unload Oxidizer RSV	Scheffler
T2K-08L58-4W		Load Cart Calibration	
T2K-08M03-4W		Less para 13.0 Fill Hose Connections	McGee

A.6 - SLC-4 Titan Example Cold Spill THZs (PHZs)

30 WS THZ plot examples are based on Appendix A.1.3 - Table 1 - Fill and Drain Flexible Hose Wetted Area Predictions. THZ Nos. are derived from Appendix F, SLC-4 Launch Complex Safety Plan. Tier 1, 2 and 3 values from the plots are summarized under PHZ examples below.

			PHZ Examples		
Booster Vehicle Loading Operation	**THZ No. (T3J-WLCSP-4C)**	**Total Wetted Area (sq ft)**	**Tier 3 (ft)**	**Tier 2 (ft)**	**Tier 1 (ft)**
Stage I Fuel, SLC-4E	1E-F	287	675	2112	N/A
Stage II Fuel, SLC-4E	1E-F	163	433	1343	N/A
Stage I Oxidizer, SLC-4E	1E-O	343	2264	8061	11780
Stage II Oxidizer, SLC-4E	1E-O	136	1314	4664	6840
Stage I Fuel, SLC-4W	1W-F	109	392	1233	N/A
Stage II Fuel, SLC-4W	1W-F	119	417	1322	N/A
Stage I Oxidizer, SLC-4W	1W-O	100	1092	3857	5648
Stage II Oxidizer, SLC-4W	1W-O	92	769	2849	4228

Note: Oxidizer - Nitrogen Tetroxide (N_2O_4)
Fuel - Aerozine 50 (A-50)